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EFFECT OF VERTICAL IRREGULARITIES ON SEISMIC PERFORMANCE OF RC BUILDINGS

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Abstract— During an earthquake, failure of structure starts at points of weakness. This weakness arises due to discontinuity in mass, stiffness and geometry of structure. The structures having this discontinuity are termed as Irregular structures. The behaviour of a building during an earthquake depends on several factors such as stiffness, adequate lateral strength, ductility and configuration. The buildings with regular geometry and uniformly distributed mass and stiffness in plan as well as in elevation suffer much less damage compared to irregular configurations. Regular buildings have uniformly distributed mass, stiffness, strength and structural form. When one or more of these properties is non-uniformly distributed, either individually or in combination with other properties in any direction, the structure is referred to as being irregular. Irregular structures contribute a large portion of urban infrastructure. Vertical irregularities are one of the major reasons of failures of structures during earthquakes.

The aim of this study is to evaluate the seismic behaviour of RC building having different types of irregularities, mainly vertical geometric irregularity and stiffness irregularity. For this study, 48 models which include vertical geometric irregular buildings (stepped buildings) with and without stiffness irregularities at different levels are modelled and analysed. To study the behaviour of the irregular structures, response spectrum analysis is conducted. The modelling and analysis are carried out using ETABS software. Parameters such as time period, lateral displacement and storey drift are studied.

Index Terms— Irregular structures, vertical irregularity, stiffness irregularity, time period, lateral displacement, storey drift

1 Introduction

Earthquakes are the most unpredictable and devastating disaster. The behaviour of a building during an earthquake depends on several factors, stiffness, adequate lateral strength and ductility, simple and regular configurations. The buildings with regular geometry and uniformly distributed mass and stiffness in plan as well as in elevation suffer much less damage compared to irregular configurations. Most recent earthquakes have shown that the irregular distribution of mass, stiffness and strengths may cause serious damage in structural systems. Structural engineer's greatest challenge in today’s scenario is constructing seismic resistant structure. The area of vertically irregular type of building is now having a lot of interest in seismic research field. Many structures are designed with vertical irregularity for architectural views. Structural design of buildings for seismic loads is primarily concerned with structural safety during major ground motions. Regular structures have uniformly distributed mass, stiffness, strength and structural form. When one or more of these properties is non-uniformly distributed, either individually or in combination with other properties in any direction, the structure is referred to as being irregular.

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Regular structure:

Regular structures have no significant physical discontinuities in plan or vertical configuration or in their lateral force resisting systems.

Irregular structure:

Irregular structures have significant physical discontinuities in configuration or in their lateral force resisting systems. They have either vertical irregularity or plan irregularity or both in their structural configurations.

2 MODELLING AND ANALYSIS

Four G+10 vertically irregular frames are considered as base models. Modelling has been carried out using ETABS V 9.7.2 program. Configuration of frames is as given below.

MODEL X1: This is the first base model of structure with set-back along X axis and having G+10 storeys, with a storey height of 4m for each floor and the bay width of 5m. The basic specifications of the building are: Dimensions of the beam = 0.3 m × 0.45 m; Column size = 0.55 m × 0.75 m.

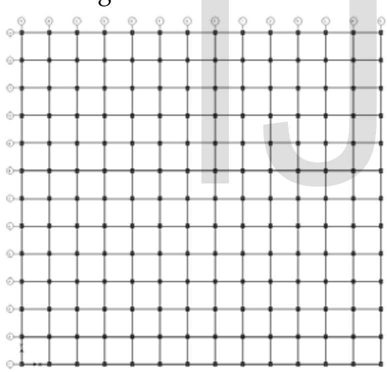
MODEL Y1: This is the second base model of structure with set-back along Y axis and the rest of the data is same as Model X1.

MODEL XY1: This is the fourth base model of structure with set-back along both X and Y axis and the rest of the data is same as Model X1.

MODEL P1: This is the fourth base model of structure with set-back along all the four sides (Stepped pyramidal type) and the rest of the data is same as MODEL X1.

There are another 44 models which includes 4 set of 11 models of structure with set-back along X axis, Y axis, both X and Y axis and all the four sides respectively. The structural data is same except of the following with respect to the base model.

Floor Height = 4.5 m



By increasing the floor height stiffness irregularity can be incorporated. The storey in which stiffness irregularity is incorporated is given in the following table.

TABLE1: Model and Storey in which stiffness irregularity incorporated

Model	Storey	Model	Storey
MODEL X2	Ground floor	MODEL Y2	Ground floor
MODEL X3	1st floor	MODEL Y3	1st floor
MODEL X4	2nd floor	MODEL Y4	2nd floor
MODEL X5	3rd floor	MODEL Y5	3rd floor
MODEL X6	4th floor	MODEL Y6	4th floor
MODEL X7	5th floor	MODEL Y7	5th floor
MODEL X8	6th floor	MODEL Y8	6th floor
MODEL X9	7th floor	MODEL Y9	7th floor
MODEL X10	8th floor	MODEL Y10	8th floor
MODEL X11	9th floor	MODEL Y11	9th floor

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MODEL X12	10th floor	MODEL Y12	10th floor
MODEL XY2	Ground floor	MODEL P2	Ground floor
MODEL XY3	1st floor	MODEL P3	1st floor
MODEL XY4	2nd floor	MODEL P4	2nd floor
MODEL XY5	3rd floor	MODEL P5	3rd floor
MODEL XY6	4th floor	MODEL P6	4th floor
MODEL XY7	5th floor	MODEL P7	5th floor
MODEL XY8	6th floor	MODEL P8	6th floor
MODEL XY9	7th floor	MODEL P9	7th floor
MODEL XY10	8th floor	MODEL P10	8th floor
MODEL XY11	9th floor	MODEL P11	9th floor
MODEL XY12	10th floor	MODEL P12	10th floor

TABLE2: Details of the model

Number of storey	G+10
Dimension of building	65 m x 60 m
Floor Height (Typical)	4.0m
Size of Beam	300 mm x450 mm
Size of Column	550 mm x 750 mm
Depth of slab	150 mm
Infill wall	230 mm thick wall
Specific weight of infill	20 KN/m^3
Specific weight of RCC	25 KN/m^3
Impose load	3 KN/m^2
Floor finish	1 KN/m^2
Partition load	2 KN/m^2
Materials	Concrete (M30) and Reinforcement Fe415

The building is considered to be located in seismic zone V. The building is founded on medium strength soil.

Response spectrum analysis is used as the method of analysis.

Fig.1 Beam Column Layout of the building

Fig.2 3-D view of MODEL X1

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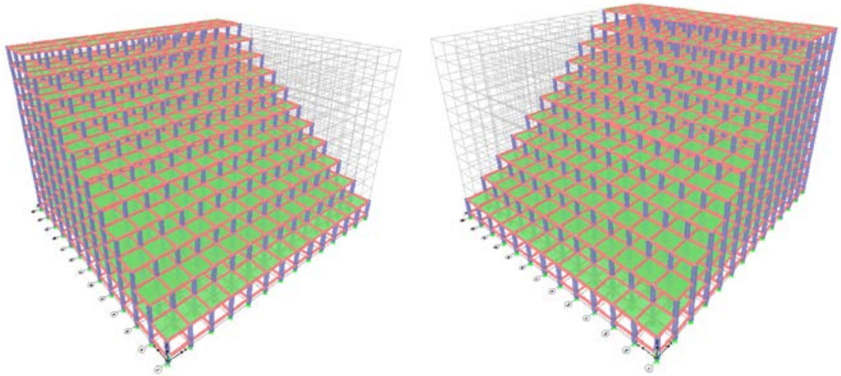

Fig.3 3-D view of MODEL Y1

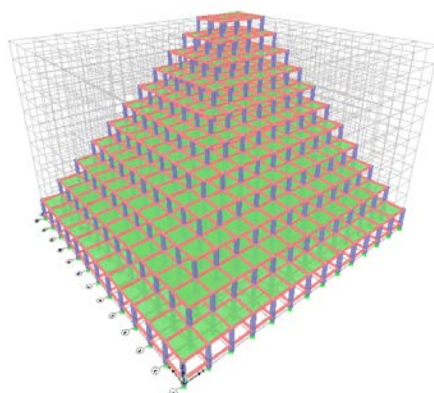

Fig.4 3-D view of MODEL XY1

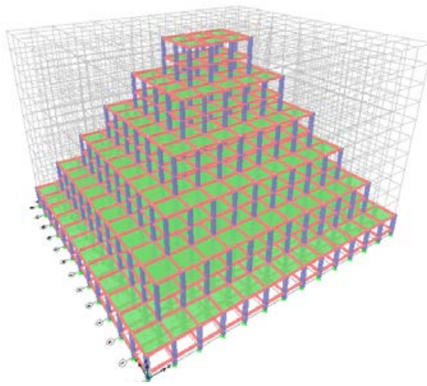

Fig.5 3-D view of MODEL P1

3. RESULTS AND DISCUSSION

3.1 Modal Analysis

Comparison of time period of the vertical geometric irregular buildings (Stepped buildings)

Table 3: Time period in sec

Case	MODEL X1	MODEL Y1	MODEL XY1	MODEL P1
X-direction	2.072341	2.242872	1.872399	1.594712
Y-direction	2.241127	1.87364	1.584347	1.487456

From this result it is clear that, the time period for the building with set-back along all the four sides (Stepped pyramidal type building) is lesser than the building with set-back along X axis, Y axis and both X and Y axis. That means stepped pyramidal type building is stiffer than the other models.

Stepped buildings have frames of different height. Thus, both mass and stiffness distribution changes along the height; the center of mass and center of stiffness of different storeys do not lie along the same vertical line, as is the case in buildings with regular overall geometry. This results in twisting of buildings which is clear from the mode shape.

Table 4: Buildings and its mode shape characteristics

Type of Building	Mode 1	Mode 2	Mode 3
Stepped pyramidal Type	X - Translation	Y - Translation	Torsion Mode about - Z
Set-back along X	Y - Translation with Torsion	X - Translation	Torsion Mode about - Z
Set-back along Y	X - Translation with Torsion	Y - Translation	Torsion Mode about - Z
Set-back along both X and Y	Torsion Mode about - Z	Torsion Mode about – Z	Torsion Mode about - Z

3.2 Response Spectrum Analysis

Comparison of storey drift for vertical geometric irregular buildings (stepped buildings) having stiffness irregularity at different levels

Storey drift for each building is compared and graph showing the variation of storey drift for each building is plotted.

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Fig.6 Graph showing the Variation of Drift X of buildings having set-back along X axis

Fig.7 Graph showing the Variation of Drift Y of buildings having set-back along X axis

Fig.8: Graph showing the Variation of Drift X of buildings having set-back along Y axis

Fig.9: Graph showing the Variation of Drift Y of buildings having set-back along Y axis

Fig.10: Graph showing the Variation of Drift X of buildings having set-back along both X and Y axis

Fig.11: Graph showing the Variation of Drift Y of buildings having set-back along both X and Y axis

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Fig.12: Graph showing the Variation of Drift X of buildings having set-back along all the four sides

Fig.13: Graph showing the Variation of Drift Y of buildings having set-back along all the four sides

By considering the storey drift, it is clear that there is an abrupt change in storey drift at the storey in which the stiffness irregularity is incorporated. And we can also see that the maximum drift occurs at lower storeys for the models with set-back along X axis and for models with set-back along Y axis. But for models with set-back along both X and Y axis and for models with set-back along all the four sides, maximum drift occurs at higher storeys.

Comparison of Displacement and storey drift of vertical geometric irregular building (stepped building)

Here building with set-back along all the four side, X axis, Y axis and both X and Y axis is denoted as MODEL P, MODEL X, MODEL Y and MODEL XY respectively.

Variation of Displacement and storey drift of the models with no stiffness irregularity, stiffness irregularity at ground floor, at 1st floor, at 2nd floor, at 3rd floor, at 4th floor, at 5th floor, at 6th floor, at 7th floor, at 8th floor, at 9th floor and at 10th floor are given in the following graphs.

Fig.14: Graph showing the variation of Displacement X of the models with set-back along all the four sides, X axis, Y axis and both X and Y axis and having stiffness irregularities at different storeys

Fig.15: Graph showing the variation of Displacement Y of the models with set-back along all the four sides, X axis, Y axis and both X and Y axis and having stiffness irregularities at different storeys

Fig.16: Graph showing the variation of Drift X of the models with set-back along all the four sides, X axis, Y axis and both X and Y axis and having stiffness irregularities at different storeys

Fig.17: Graph showing the variation of Drift Y of the models with set-back along all the four sides, X axis, Y axis and both X and Y axis and having stiffness irregularities at different storeys

By considering the displacement we can see that, Displacement in X direction is more for the models with set-back along Y axis. Similarly Displacement in Y direction is more for the models with set-back along X axis.

And also the displacement and drift values along both directions for buildings with set-back along four sides are less compared to other building.

4. CONCLUSION

From modal analysis, it is clear that the fundamental time period of the stepped pyramidal structure is lesser compared to set-back buildings in X, Y and XY direction. And we can also see that torsional effect is predominant in the buildings with set-back along X, Y and XY direction as compared to the stepped pyramidal structure.

By considering the storey drift it can be inferred that the stiffness irregularity in each storey causes an abrupt change in the storey drift. So it can be concluded that the vertically irregular building with stiffness irregularity is susceptible to damage in earthquake prone zone. The vertically irregular building develops least storey drifts while the building with stiffness irregularity on vertically irregular building shows maximum storey drift on the respective storey levels.

By considering the displacement we can see that, Displacement in X direction is more for the buildings with set-back along Y axis. Similarly Displacement in Y direction is more for the buildings with set-back along X axis.

Displacement and drift values along both directions for buildings with set-back along all the four sides are less compared to other buildings which means buildings with set-back along all the four sides are more stable than other buildings.

The analysis proves that vertically irregular structures are more susceptible to damage and the effect of stiffness irregularity on the vertically irregular structure is also dangerous in seismic zone. Therefore, as far as possible irregularities in a building must be avoided. But, if irregularities have to be introduced for any reason, they must be designed properly following the conditions of IS 1893 (Part-1): 2002 and IS- 456: 2000, and joints should be made ductile as per IS 13920:1993

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